# 17th ICCRTS
## "Operationalizing C2 Agility"

# Light models of civilian support in Blue-Red operations

## Topic: Modeling and Simulation

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## Abstract

Computationally simple, yet informative, "light" agent-based models are useful understanding mechanisms for complex phenomena lacking theoretical grounding. A light model, as a simplified set of attributes and interactions, can generate insight and be credible to specific audiences. Embedded within large force-on-force simulations a light model of civilian support could offer command-level decision makers a lens for viewing (and mitigating) the effects of direct action within highly populated areas of operation. This investigation utilizes Matlab as a prototyping language to construct a light agent-based model and sandbox for developing and testing mathematical representations of civilian support during Blue-Red operations. The model minimalistically produces fluctuating levels of commitment, fear, and anger towards Blue or Red force in response to firing actions. The results of several experimental model runs are presented categorized by different levels of targeting effectiveness and accuracy.

## 1. Introduction

Gaining and maintaining support of the civilian population throughout an operation is a formidable challenge (FM 3-24, 2006; Galula, 1964). Combating forces vie for popular support from a relatively uncommitted populace using a variety of conventional and unconventional tactics. While the strategies differ significantly, the ultimate goal is to convince the population to support one or the other combating forces. These types of power struggles characterize the dynamics of civil rebellion, guerrilla warfare, and counterinsurgency.

Modeling and simulation techniques have been utilized to study social processes such as the dynamics between opposing actors in a conflict. Common modeling approaches include game theory, system dynamics, conflict resolution, influence modeling, and agent-based modeling (e.g., Bhavnani, Miodownik, & Nart, 2008; Epstein, 2002; Israel & Peugeot, 2011; Lafond & DuCharme, 2011; Louie & Carley, 2007; Ruby, Sallach, Macal, Mellarkod, & Wendt, 2005; Sato, Kubo, & Namatame, 2011; Shvartsman & Taveter, 2011). These approaches typically model interactions at a strategic level which is sufficient for representing opposing actor conflicts in fields such as political science and sociology. At a more detailed unit and tactical level, strategic interactions are modeled with complex battlefield scenarios on large force-on-force simulations such as OneSAF (http://www.onesaf.net/community/). Modeling of this type can assist military planners and analysts assess the implications of different courses of action over time.

Fine-grain modeling of operations at the tactical level with force-on-force simulations requires substantial computational resources. With limited computational resources available, a representation of the civilian population in a simulated area of operations is often absent or very minimal. Sometimes, civilians may play the part of distracter targets or as an end of scenario collateral damage metric. This raises the question: What model of civilian support would offer situational awareness of the local populace without substantially increasing computational complexity when embedded within a force-on-force simulation?

Considering the above question, the paper is organized as follows. Section 2 defines a light agent-based representation of a civilian. The attributes of the civilian agent support the formulation of a commitment metric. Shifts in civilian commitment occur in response to parametric controlled direct action. Outcomes from direct action such as casualties and social disruption impact civilians by changing their level of commitment as explained in Section 3. Section 4 describes the Matlab environment constructed to iteratively develop and test the civilian model. Several experimental model runs categorized by effectiveness and accuracy in targeting are presented. Section 5 concludes the paper by summarizing the purpose of the investigation and suggesting future directions.

## 2. A 'Light' Civilian Agent

Gaining the support of an adequate portion of the civilian population in an area of operations can be critical to the success of the mission. Large combat simulations should include a representation of civilians for monitoring and identifying predictable patterns of support. If an agent-based modeling approach is used, individual civilian agents can be represented at a simplistic or 'light' level capturing an essential set of characteristics or attributes. The set of attributes defining an agent requires careful consideration. Each attribute will increase the complexity of the simulation, the required computational resources, the size of the parameter space, and the number of assumptions needed for interpreting useful model output. The attributes should support the answering of 'what if' questions posed by the decision makers and analysts utilizing the simulation. Agent attributes commonly store information about the location and state of the agent. Behavioral attributes can vary significantly in describing the general character of the agent, its intentions, and even psychological, cognitive, and physical characteristics.

For this study, a civilian agent was constructed with the attributes listed in Table 1. The attributes *xpos* and *ypos* record the current position of the civilian on a two-dimensional grid battlefield. The *state* attribute records the civilian as alive or dead. The *fear* and *anger* attributes record the degree of fear and anger towards the combating forces. In Table 1, *B* is for Blue force representing government or pro-government, and *R* is for Red force representing anti-government. The range of values for *fear* and *anger* are 0 to 1.0. Fear and anger only increase in value, and are bounded at a maximum of 1.0. An increase in the value of fear or anger signifies an increase in the degree of fear or anger felt towards the denoted force. For example, a *B-anger* value of 0 indicates the civilian agent is not at all angry at the Blue force, while a *B-anger* value of 1 indicates maximum anger towards the Blue force. Another example, if *B-fear* is 0.47 and *R-fear* is 0.31, then the civilian is more fearful of Blue force than Red force.

Table 1: Attributes defining the civilian agent.

| Attribute Name | Meaning |
|---|---|
| xpos | X position on grid |
| ypos | Y position on grid |
| state | Alive or dead |
| B-fear | Fear of Blue |
| R-fear | Fear of Red |
| B-anger | Anger toward Blue |
| R-anger | Anger toward Red |
| viothres | Violence threshold |
| commit | Commitment (total) |
| commitHL | Commitment (human loss) |
| commitSD | Commitment (social disruption) |

The *viothres* attribute represents a propensity to use violence under certain circumstances. For example, an insurgent is essentially a civilian willing to engage in violence against Blue force soldiers. Under the right conditions (i.e., combination of *fear*, *anger*, and *viothres* values) a civilian may become a potential threat. Similar to fear and anger, the range of values for *viothres* is 0 to 1.0. A *viothres* value of 0 characterizes a civilian with a low threshold to commit violence. This means the civilian is willing to use violence under many circumstances. A *viothres* value of 1 characterizes a civilian with a high violence threshold who is reluctant to turn to violence.

Variations of the fear, anger, and violence threshold attributes have been utilized by researchers within the political science computational modeling community (e.g., Bennett, 2008; Findley & Young, 2006; Wheeler, 2005).

The remaining three attributes indicate how committed the civilian agent is to either Blue or Red force. Commitment can be defined as “the act of binding yourself (intellectually or emotionally) to a course of action” (http://www.thefreedictionary.com/commitment). For this light civilian model, commitment is acting as the baseline behavior of support. The civilian must be committed to the cause before actively contributing support to one of the combating forces.

The two commitment attributes shown at the bottom of Table 1 (*commitHL and commitSD*) are used to formulate a total commitment value. The human loss component of commitment (*commitHL*) is calculated from the number of shots fired and number of soldiers and civilians killed. The social disruption component of commitment (*commitSD*) is calculated from the number of indirect fire attempts and IED detonations. These are combined in the *commit* attribute. The range of values for the commitment attributes is -1.0 to 1.0. Commitment attributes can both increase and decrease from an initial starting value, but are bounded within a range of -1.0 to 1.0.

Figure 1 visualizes the commitment scale using an insurgency scenario. A commitment value at the positive end of the scale represents a civilian dedicated to government and pro-government forces (Blue force). As the commitment value nears 1.0, the civilian may become a potential provider of support and intelligence to pro-government forces. A commitment value at the negative end of the scale represents a civilian dedicated to an anti-government cause (Red force). As the commitment value nears -1.0, the civilian may become a threat to the government or a latent insurgent. Civilians with commitment falling at the far ends of the continuum are not easily dissuaded in their views. The majority of civilian commitment lies in the middle of the scale being weakly supportive of one side or the other. These civilians are susceptible to influence from either extreme based on the actions of the combating forces.

The scale in Figure 1 is applied at the individual civilian agent level. The same scale can be applied at the aggregate level by super imposing a civilian commitment distribution on the -1.0 to 1.0 continuum. For example, in a stable society the commitment distribution might be weighted heavily towards the positive end of the scale supporting the government and pro-government forces. A secondary portion of this distribution may be passive in their support with a fringe element opposes the government. In an insurgency scenario, the commitment distribution might be weighed heavily towards the negative end of the scale supporting the insurgents and their cause with a secondary portion as passive and a fringe element opposing the insurgency.

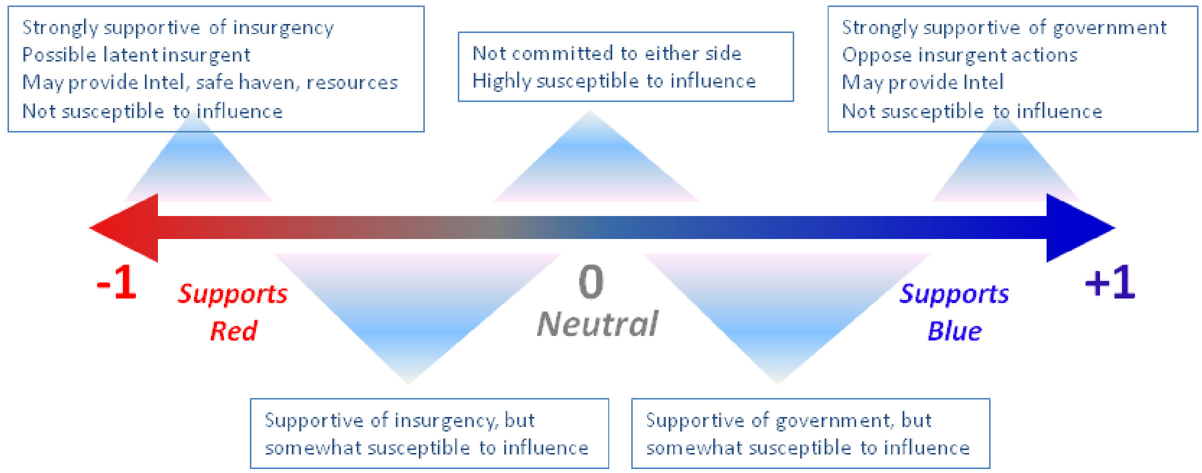



Figure 1: The civilian commitment continuum.

At the beginning of a simulation run, the civilian commitment distribution is initialized to represent the current state of commitment at mission startup. For example, if humanitarian projects were executed beforehand such as building shelters or increasing the supply of drinking water, commitment might be positioned towards the positive end of the scale—supportive of Blue force. The bottom half of Figure 2 shows an example initial civilian commitment distribution resulting from pre-mission humanitarian efforts with a mean commitment of approximated 0.5. The commitment distribution can also reflect a variety of conflict intensities: Humanitarian Assistance (HA), Peace Enforcement (PE), Counter Insurgency (CI), and Combat (CMB). In the top half of Figure 2, the second distribution from the right illustrates civilian commitment resulting from PE with a mean of -0.25, slightly anti-government or supportive of an insurgency cause. As the intensity of conflict increases, the commitment distribution slides towards the negative end of the continuum.

Obviously, shifts in commitment attribute values of individual civilian agents change the civilian commitment distribution. At the group level of analysis, the civilian commitment distribution can be tracked over time as mission-related direct actions occur.

The concept of popular support appears throughout counterinsurgency/insurgency research (e.g., Baker, 2006; Findley & Young, 2006; Ford, 2005; McGuire, 2008; McNeil, 2010; Sato, Kubo, & Namatame, 2011; Wendt, 2005; Wheeler, 2005). Findley and Young (2006) utilized the terminology ‘commitment’ in their explanation of why ‘war of attrition’ and ‘hearts and minds’ approaches have mixed effects in counterinsurgency warfare.

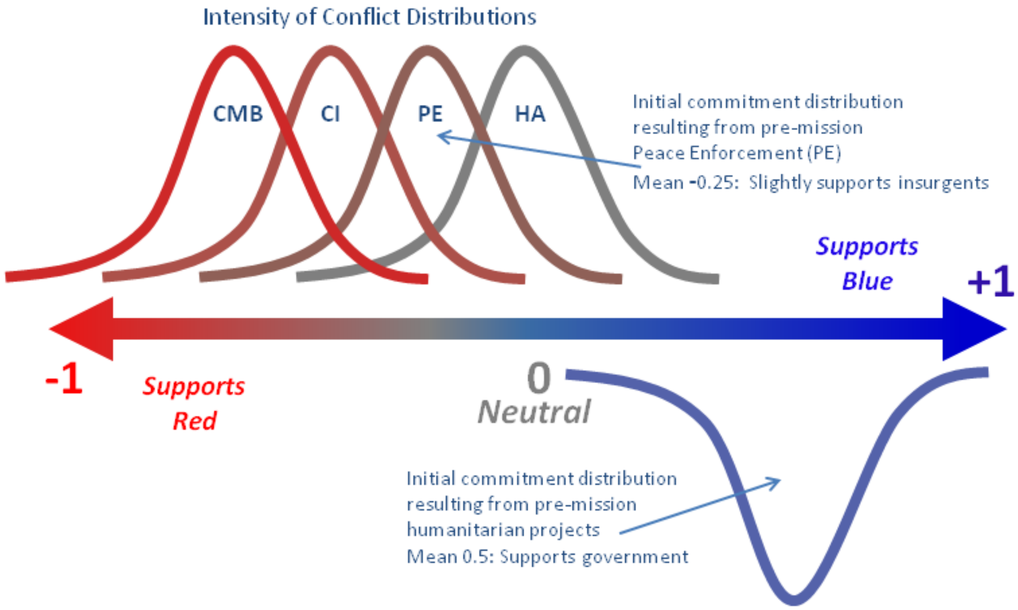



Figure 2: Example civilian commitment distributions.

## 3. Parametric-controlled Direct Action

The potential impact of direct action, such as firing on the opposing force or unintentionally killing civilians, is captured in the civilian agent's set of attributes. It is important to remember the commitment attributes represent a simplification of the complex behaviors determining popular opinion and support for the combating forces. The outcomes of direct action will shift the civilian commitment towards either Blue or Red force.

The direct action of firing, especially within a populated area, generates undesirable outcomes yielding many analysis possibilities. Ratios and indexes have been developed for systematically identifying particularly undesirable war outcomes inflicted on civilian populations during armed conflict (e.g., Coupland & Meddings, 1999; Hicks & Spagat, 2008; Sondorp, 2008). Typically, absolute numbers are utilized (e.g., civilian deaths, civilians wounded, opponent combatants killed, total killed) in a ratio format sometimes categorized by weapon type or combatant group. These counts lend themselves to comparisons over time, between courses of action, weapon types, wars, and warring combatant groups.

In this model, absolute numbers in the form of accumulated counts are used as inputs for calculating the commitment attribute values. As described in Section 2, the civilian commitment attribute (*commit*) is formulated using two subcomponents. The human loss component (*commitHL*) is derived from the number of civilians killed as collateral damage caused by the opposing forces. The social disruption component (*commitSD*) is derived from the outcomes of indirect fire and the number of IED detonations.

Two parameters are used to control the level of fidelity during an exchange of fire. A pair of parameters, called *Effectiveness* and *Accuracy* is assigned to each force: Red Effectiveness and Red Accuracy; and Blue Effectiveness and Blue Accuracy. Both effectiveness and accuracy values have the range 0 to 1. The effectiveness parameter represents the probability of killing a target when a shot is taken. For example, a

Blue Effectiveness value of 0.80 means that 80% of the time when Blue fires at a Red target, Red is killed. The accuracy parameter represents the probability of avoiding collateral damage with 1-accuracy as the probability of inflicting collateral damage. For example, a Blue Accuracy value of 0.60 means that 40% of the time when Blue fires at Red, a civilian will be killed by mistake.

The effectiveness and accuracy parameters control firing executed at an individual agent level where the outcome is either a single kill or a miss. To extend direct action for multiple kills and area destruction outcomes, a parameter switch controls the availability of indirect fire and IEDs. A second parameter controls their frequency of use. The frequency of use is typically set to a very low value because of the extensive damage caused by these actions. Indirect fire is aiming and firing in a high trajectory without relying on a direct line of sight between the gun and its target. Larger, longer range weapons such as howitzers and mortars are utilized for indirect fire. Historically, more combat deaths have been caused by indirect fire weapons than by any other means. IEDs, improvised explosive devices, are lethal varieties of roadside, truck-mounted, and suicide bombs used by anti-government forces. The Pentagon calls the IED "the single most effective weapon" used against the coalition.

Table 2 summarizes the accumulated direct action outcomes used as input for calculation of the commitment components. The human loss component (*HL*) uses the number of civilians killed by Red (*RkillCiv*) and Blue (*BkillCiv*). The social disruption component (*SD*) uses the total number of shots fired by Red (*RtShots*) and Blue (*BtShots*) and the number of indirect fires by Blue (*Bidf*) and IED detonations by Red (*Ried*). The indirect fire and IED counts are translated into an area of destruction value using the size of the agents' scan area in number of grid cells. The area of destruction values are added to the total number of shots fired for each force.

Table 2: Direct action outcome counts as input to agent commitment attributes: human loss (HL) and social disruption (SD).

| Commitment Attribute | Direct Action Outcome Counts |
|---|---|
| HL | Civilians killed by Red (RkillCiv) |
| HL | Civilians killed by Blue (BkillCiv) |
| SD | Total shots fired by Red (RtShots) |
| SD | Total shots fired by Blue (BtShots) |
| SD | IED detonation by Red (Ried) |
| SD | Indirect fire by Blue (Bidf) |

Using several of the counts listed in Table 2, commitment components are calculated as shown in Table 3. Commitment can be calculated once at the end of the model run, or at specified intervals throughout the run using the simulation clock. The equations in Table 3 are example pseudocode implementations of commitment equations for Red direct action effects. The equations for Blue direct action effects are similar. The sets of equations are modularized within a function to allow easy modification and testing of different equations.

Table 3: Example commitment equations using outcome counts
in Table 2 from Red direct action.

```
Update human loss component of commitment for each civilian

If Red kills civilians during this interval and ...
   this civilian is currently committed to Blue

CivAgs(ind).commitHL = CivAgs(ind).commitHL + perRkills *
   (1 - CivAgs(ind).commitHL);

this civilian is currently committed to Red

CivAgs(ind).commitHL = CivAgs(ind).commitHL - perRkills *
  (-1 - CivAgs(ind).commitHL);

Update social disruption component of commitment for each civilian

If Red fires or detonated IED during this interval and ...
   this civilian is currently committed to Blue

CivAgs(ind).commit = CivAgs(ind).commit + perRdes *
  (1 - CivAgs(ind).commit);

this civilian is currently committed to Red

CivAgs(ind).commit = CivAgs(ind).commit - perRdes *
  (-1 - CivAgs(ind).commit);
```

In the human loss commitment calculation (top half of Table 3), the `perRkills` variable is the number of civilians killed by Red (`RkillCiv` from Table 2) during the specified time interval. `perRkills` is in percentage format of the maximum number of civilians represented in the model run. In the social disruption commitment calculation (bottom half of Table 3), the `perRdes` variable is a sum of the number of shots fired by Red (`RtShots` in Table 2) and an area of destruction factor based on IED detonations (`Ried` from Table 2). If the time interval is a step size of the length of the model run, then the above equations include the addition or subtraction of a response-to-human-loss factor and a response-to-social-disruption factor. These response factors can be used to adjust the scale of the commitment updates.

Accumulated direct action outcomes are also used as input for the calculation of civilian fear and anger attributes. Table 4 lists the outcome counts required for calculating the pairs of fear and anger attributes, and Table 5 shows example pseudocode equations for updating these attribute values.

Table 4: Outcome counts as input to fear and anger attributes with
example updating equations.

| **Attribute** | **Direct Action Outcome Counts** |
|---|---|
| Rfear | Blue killed by Red |
| Bfear | Red killed by Blue |
| Ranger | Civilians killed by Red |
| Banger | Civilians killed by Blue |

Table 5: Example equations for updating civilian fear and anger attributes.

```
Update civilian fear attribute

If Blue kills Red during this interval
   nearby civilians become more fearful of Blue

CivAgs(ind).Bfear = CivAgs(ind).Bfear + fearInc *
(1 - CivAgs(ind).Bfear);

Update civilian anger attribute

If Blue kills a civilian during this interval
   nearby civilians become more angry towards Blue

CivAgs(ind).Banger = CivAgs(ind).Banger + angerInc *
(1 - CivAgs(ind).Banger);
```

The example equations in Table 5 increase the current values of the fear and anger attributes by a response factor similar to those applied to human loss and social disruption. Response factors *fearInc* and *angerInc* are assigned values at the beginning of the model run to adjust the scale of the attribute updates. Unlike the range of values for commitment (-1 to 1), fear and anger attribute values are bounded by 0 and 1 with 0 meaning no fear or anger, and 1 meaning maximum fear or anger. For example, the civilians' fear and anger shifts 10% of the way towards 1.0 from their current level of fear and anger (when parameters *fearInc* and *angerInc* are set to 0.10 in the Table 5 equations).

The fear, anger, and violence threshold attributes for all civilian agents are initialized at the beginning of the model run using distributions similar to those described in Figure 2. The fear and anger attribute values dynamically shift upwards during the course of the model run as a result of direct action outcomes. In this model, there is no situation causing a downward shift in fear and anger. The violence threshold attribute is static, staying at the initially assigned value throughout the model run. The fear, anger, and violence threshold attribute values can be tracked and analyzed at both the individual civilian agent level and the group level by aggregate analysis techniques and distribution comparisons. The combined attribute values work together in determining a civilian's negative emotions towards the opposing forces. For example, Figure 3 shows a sequence of relationships between a civilian agent's fear, anger, and violence threshold attributes in response to several direct actions listed in Table 4.

In Figure 3, Step 0 shows the initial state of a civilian's fear and anger toward both Red and Blue, and the violence threshold. As direct actions occur civilians shift their fear and anger towards 1.0 from the current position. The violence threshold, a civilian's propensity for violence, is not affected by direct action. The position of the attributes in Step 0 indicates the civilian feels more fearful and angry at Red force then Blue force. At this point, none of the attributes have exceeded the violence threshold.

In Step 1, a Red force soldier shoots and kills a Blue force soldier. If this occurs within a civilian's scan area, fearfulness of Red force increases (Red 'F' shifts towards 1.0). Although fear of Red has now exceeded the violence threshold, the civilian is not a potential threat because the level of anger towards Red is still below the violence threshold.

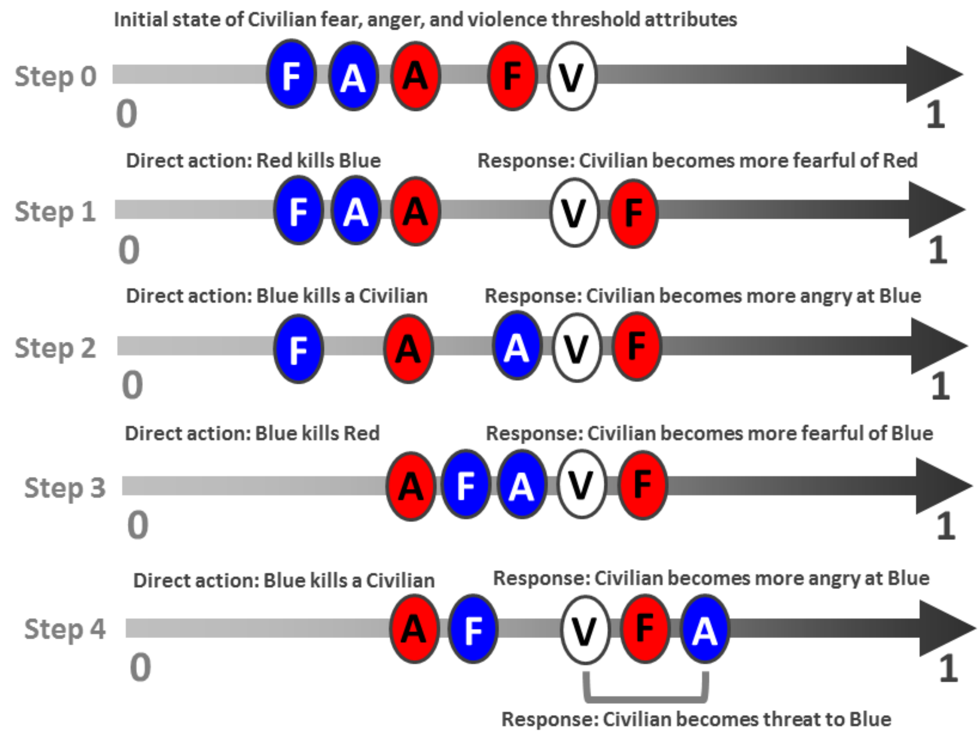



Figure 3: Sequence of civilian attributes in response to direct action: fear ('F'), anger ('A'), and violence threshold ('V'). Fear and anger: towards Red represented by red ovals with black letters; towards Blue represented by blue ovals with white letters.

In Step 2, a civilian is accidently killed by a Blue force soldier. For civilians nearby, this action increases their level of anger towards Blue (Blue 'A' shifts towards 1.0). In Step 3, a Blue force soldier kills a Red soldier. In response, the civilian becomes more fearful of Blue (Blue 'F' shifts towards 1.0).

In Step 4, another civilian is killed by Blue force. The level of anger towards Blue in the previous step was slightly under the violence threshold. Now, in response to another accidental civilian death, anger towards Blue exceeds the violence threshold (Blue 'A' shifts towards 1.0). If a civilian is more angry then fearful, and the civilian's anger passes the violence threshold, then the civilian becomes a potential threat to Blue force. This condition represents a civilian who is angry enough at Blue force, but not so fearful of Blue force; that if given the opportunity the civilian may attack a Blue soldier.

In keeping with a light-agent formulation, these stylized civilians lack many real world qualities. The benefit of an incomplete representation is a model of reduced complexity and manageable parameter space. In complex models fundamental patterns can become lost as the parameter space for evaluation grows, possibly concealing the dynamics of interest. In short, more complicated models are more difficult to understand. For iterative development and testing of a light civilian agent, a reduced simulation environment is adequate for exercising the agent. The next section describes a minimal agent-based simulation environment implemented in Matlab.

## 4. The Simulation

In this investigation, the simulation environment includes two types of agents: civilians and soldiers. There is no distinction between Blue force and Red force soldiers except for their color on the battlefield. Similar to civilians, soldier agents have *xpos* and *ypos* attributes to record their current position, and a *state* attribute to record the soldier as alive or dead. Soldier agents do not possess any behavioral attributes, and can perform only limited combat behavior (i.e., firing). Firing behavior is controlled by the effectiveness and accuracy parameters as discussed in Section 3.

Soldiers move around a square 2-dimensional grid of cells representing a battlefield. Civilians do not move; staying in their randomly placed initial grid position for the duration of the simulation. The size of the battlefield grid is adjustable. The example runs described in this section use a small battlefield grid of 50 x 50 cells. The battlefield has edge boundaries; it is not a torus. The terrain is flat and devoid of any natural or man-made obstacles. At start up, Red, Blue, and civilian agents, each as a group, can be positioned on the battlefield within a pre-defined bounded box. Within each box, the agents are placed randomly. Each agent in the simulation occupies one grid cell, and only one agent can occupy any one cell at a time. Currently, there is a constraint of an equal number of Blue to Red soldiers simulating symmetric combat. In the example runs, the number of civilians substantially out number both Blue and Red soldiers.

Agents' situated awareness is defined by a scan area. In the example runs, all agents have a 9 x 9 cell scan area with the agent positioned in the center cell. The default behavior for soldiers is a one cell move in a random direction per simulation tick. Before soldiers execute this move, they evaluate their scan area searching for soldiers of the opposing force. If an opposing soldier is detected, and this soldier is positioned in a direct line of sight (defined by a vertical, horizontal, or diagonal path), a firing behavior is executed. If the detected opposing soldier is not in a direct line of sight, then a move of one cell towards the detected soldier is executed in the hopes of gaining a direct line of sight on the next tick. Whether the targeted soldier is successfully killed depends on the effectiveness parameter, and the probability of accidently shooting a civilian depends on the accuracy parameter.

As explained in Section 3, the availability and frequency of use of indirect fire and IEDs is parametrically controlled. If indirect fire or an IED is scheduled for execution, a scan area-sized target is searched for containing more than one opposing force soldier with no instances of friendly fire. The number of civilians located in the selected target area is not considered except in an after action dead count.

When a soldier or civilian agent is killed, its *state* attribute value changes from 1 to 0 reflecting a dead state, and the agent's color representation on the battlefield changes to black. As discussed in Section 2, if civilians witness the shooting of Blue and Red soldiers within their scan area, they experience an increase in fear; if they witness the shooting of other civilians in their scan area, they experience an increase in anger. In addition, the level of civilian commitment shifts in response to firing at a rate proportional to the number of civilians killed.

Table 6 summarizes model parameters, the range allowable for each parameter, and several of the default values used in the example runs shown in this section. The key parameters systematically varied in the model runs are noted by an asterisk.

Table 6: Summary of key simulation parameters.

| Parameter | Scope | Definition | Range | Default Value |
|---|---|---|---|---|
| Battlefield size | Global | Dimensions of grid | 1+ | 50 |
| Agent scan area | All Agents | Agents' situated awareness | 3+ | 9 |
| Red effectiveness | Red Agents | Probability of killing targeted Blue soldier | 0 to 1.0 | 0.2 * |
| Red accuracy | Red Agents | (1-accuracy) probability of killing civilian instead of targeted Blue soldier | 0 to 1.0 | 0.2 * |
| Blue effectiveness | Blue Agents | Probability of killing targeted Red soldier | 0 to 1.0 | 0.8 * |
| Blue accuracy | Blue Agents | (1-accuracy) probability of killing civilian instead of targeted Red soldier | 0 to 1.0 | 0.8 * |
| Indirect fire and IEDs | Global | Available for use by opposing forces | 0 or 1 | 1 * |
| Frequency indirect fire and IEDs | Global | Frequency of use by opposing forces | 0 to 1.0 | 0.05 * |
| Initial Red Fear | Civilian Agents | Level of civilian's initial fear of Red | 0 to 1.0 | M=0.5 SD=0.25 |
| Initial Red Anger | Civilian Agents | Level of civilian's initial anger towards Red | 0 to 1.0 | M=0.25 SD=0.125 |
| Initial Blue Fear | Civilian Agents | Level of civilian's initial fear of Blue | 0 to 1.0 | M=0.5 SD=0.25 |
| Initial Blue Anger | Civilian Agents | Level of civilian's initial anger towards Blue | 0 to 1.0 | M=0.25 SD=0.125 |
| Violence Threshold | Civilian Agents | Level anger must exceed for civilian to become a threat | 0 to 1.0 | M=0.6 SD=0.125 |
| Fear increment | Civilian Agents | Amount fear increases if witnesses killing of opposing forces | 0+ | 0.10 |
| Anger increment | Civilian Agents | Amount anger increases if witnesses killing of other civilians | 0+ | 0.10 |
| Initial commitment | Civilian Agents | Level of civilian's initial commitment towards opposing forces | -1.0 to 1.0 | M=0 SD=0.15 * |
| Human loss commitment increment | Civilian Agents | Amount human loss changes in response to direct action | 0+ | 0.02 |
| Social disruption commitment increment | Civilian Agents | Amount social disruption changes in response to direct action | 0+ | 0.01 |

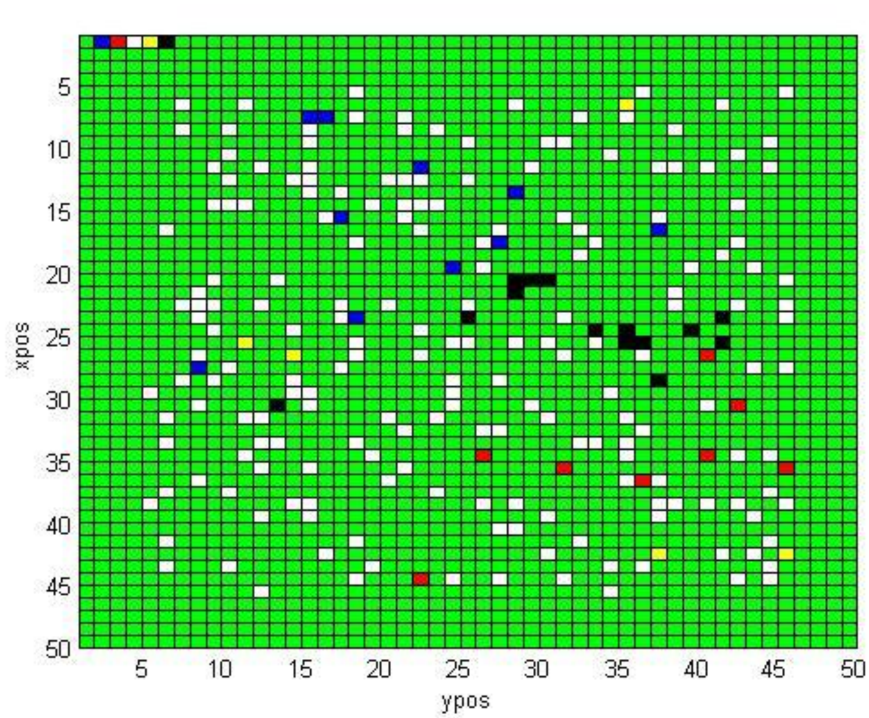
## *Basic Model Runs*

To illustrate the dynamics of the simulation, several one-run scenarios are described below. The scenarios use different combinations of effectiveness, accuracy, indirect fire/IED availability, and initial commitment distributions.

### Scenario 1: High Effectiveness (0.8), High Accuracy (0.8) for both Blue and Red

In this scenario, both Blue and Red force soldiers have high effectiveness and accuracy when firing. The initial distributions of civilian fear, anger and violence threshold are set to the values shown in Table 6. These initial behavior attribute distributions will remain constant across all of the described scenarios. The initial commitment distributions, both the human loss and social disruption components, are sampled from a distribution with mean = 0 and standard deviation = 0.15. This represents a populace where the majority of civilians have a neutral level of commitment—not committed to either Blue or Red. These civilians are highly susceptible to influence from either force. The simulation is run once without the availability of indirect fire and IEDs (Figure 4a), and then again with the availability of indirect fire and IEDs (Figure 4b). The length of a model run is 100 ticks. There is an initial population of 200 civilians. Both Blue and Red force consist of 15 soldiers each.

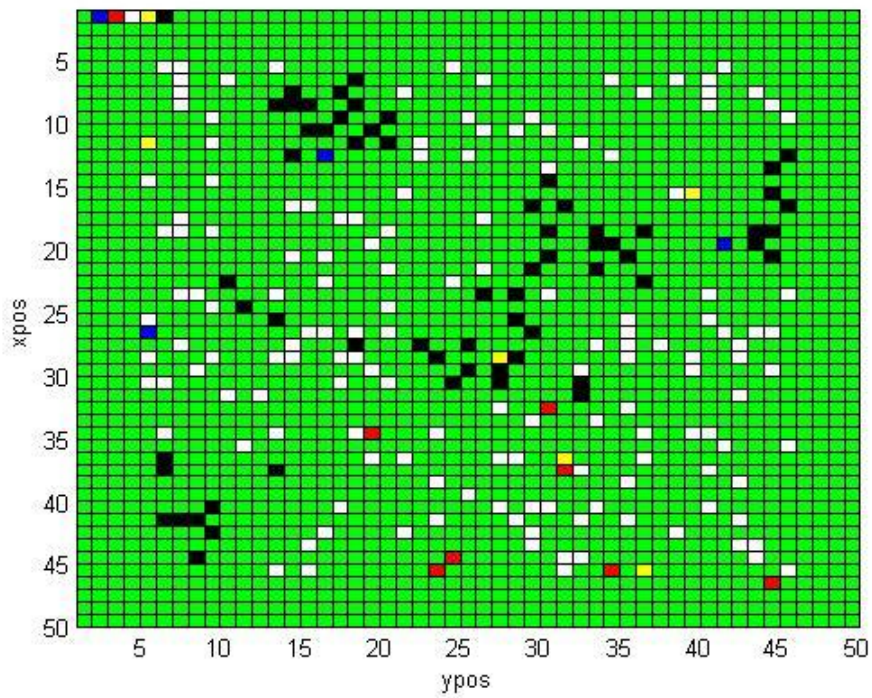
Figure 4a shows the battlefield at the end of the first run with no indirect fire or IEDs in use. At the bottom of the figure several final statistics are listed. In comparison, Figure 4b shows end state of the second run with indirect fire and IEDs in use. In the figures, the upper left hand corner of the battlefield contains a color map. Blue and Red colored cells represent the soldier agents. White cells are the civilian agents. Black colored cells are dead soldiers and civilians. Yellow colored cells represent civilians who are a potential threat (i.e., their level of anger has exceeded their fear and threshold for violence).




| | |
|---|---|
| Red killed by Blue = 7 | Blue killed by Red = 5 |
| Shots fired by Blue = 7 | Shots fired by Red = 5 |
| Civilians killed by Blue = 1 | Civilians killed by Red = 2 |
| Mean initial commitment = 0.005 | Mean final commitment = 0.013 |
| Civilian threats against Blue = 2 | Civilian threats against Red = 3 |

Figure 4a: Scenario 1, Run 1: both Blue and Red: Effectiveness = 0.8, Accuracy = 0.8; neutral initial level of commitment; no use of indirect fire or IEDs. End state of the battlefield grid (top); final statistics (bottom).

When both effectiveness and accuracy are high; shots fired on the opposing force successfully kill their intended target with few civilian causalities. The final statistics in Figure 4a show Blue fired seven times resulting in seven dead Red soldiers, and Red fired five times resulting in five dead Blue soldiers. Only one civilian is killed by Blue, and two civilians by Red. There is little change in the level of civilian commitment from the initial to final mean. Two civilians are a potential threat to Blue soldiers and three civilians are a potential threat to Red soldiers.




| | |
|---|---|
| Red killed by Blue = 8 | Blue killed by Red = 12 |
| Shots fired by Blue = 4 | Shots fired by Red = 4 |
| Blue indirect fire attempts = 2 | Red IED detonation attempts = 3 |
| Civilians killed by Blue = 15 | Civilians killed by Red = 29 |
| Mean initial commitment = 0.005 | Mean final commitment = 0.272 |
| | Mean final human loss = 0.238 |
| | Mean social disruption = 0.083 |
| Civilian threats against Blue = 3 | Civilian threats against Red = 2 |

Figure 4b: Scenario 1, Run 2: both Blue and Red: Effectiveness = 0.8, Accuracy = 0.8; neutral initial level of commitment; use of indirect fire and IEDs. End state of the battlefield grid (top); final statistics (bottom).

Figure 4b shows the results with the use indirect fire and IEDs (2 indirect fire, 3 IED detonations). There is an increase in the soldier death count (12 in Run 1 compared to 20 in Run 2) and civilian casualties (3 in Run 1 compared to 44 in Run 2). There is a substantial shift of commitment towards Blue force, mostly because Red force killed almost twice as many civilians (0.0 initial commitment compared to 0.27 final commitment). Most of the commitment shift appears within the human loss component from civilians witnessing other civilians being killed. Figure 5 shows histograms of the initial and final commitment distributions.

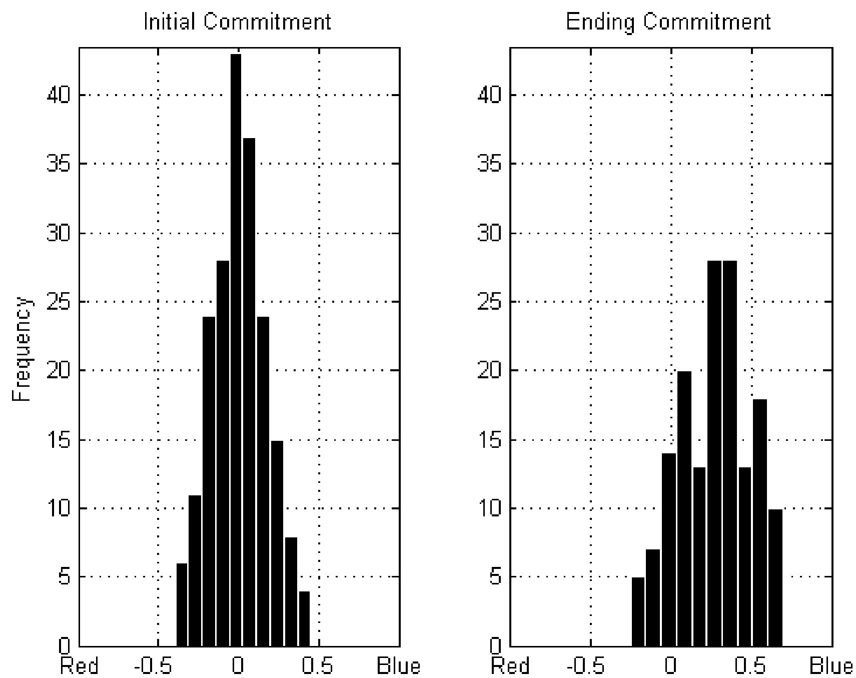
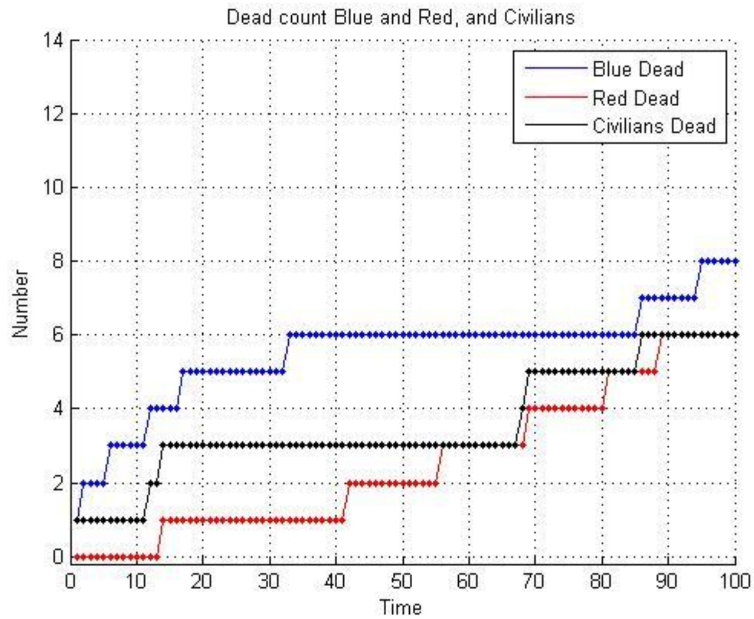



Figure 5: Initial commitment (left) and final commitment (right) distributions from Scenario 1, Run 2. Civilian commitment shifts towards Blue force in response to civilian deaths resulting from Red force direct actions.

**Scenario 2: High Effectiveness (0.8), High Accuracy (0.8) for Blue**
**High Effectiveness (0.8), Low Accuracy (0.2, high collateral damage) for Red**

In this scenario, Blue force soldiers have high effectiveness and accuracy; and Red force soldiers have high effectiveness but low accuracy. Low accuracy increases the probability for collateral damage. Indirect fire and IEDs are not available for use in this scenario. The initial commitment distribution is shifted slightly towards Blue force with mean = 0.25 and standard deviation = 0.15. This commitment distribution represents a populace more supportive of Blue force than Red force, but still susceptible to influence from either force.

The Matlab simulation environment produces a variety of plots recording responses to direct action occurring during a model run. Figure 6 shows a plot of soldier and civilian dead counts (top) and a plot of mean civilian fear and anger attribute values (bottom). Final statistics from the run are displayed in the text box between the plots.




| | |
|---|---|
| Red killed by Blue = 6 | Blue killed by Red = 8 |
| Shots fired by Blue = 6 | Shots fired by Red = 8 |
| Civilians killed by Blue = 2 | Civilians killed by Red = 4 |
| Mean initial commitment = 0.25 | Mean final commitment = 0.32 |

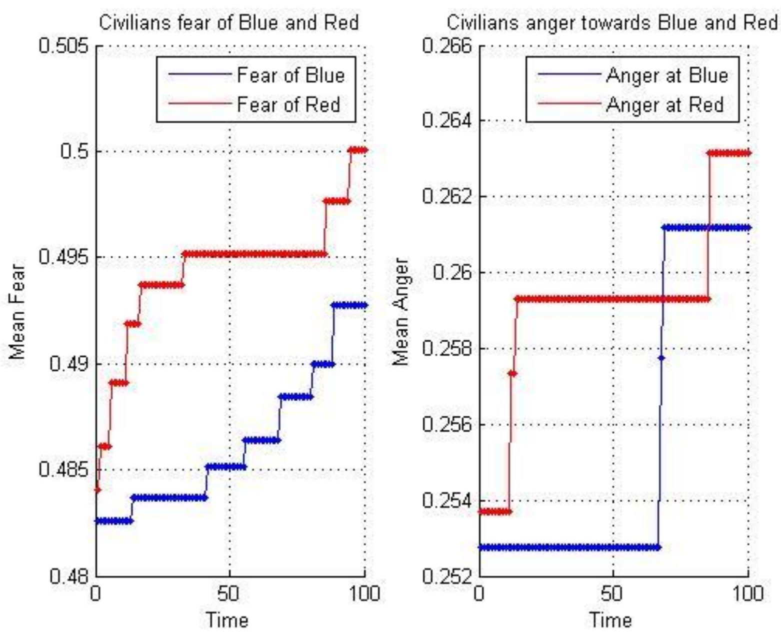
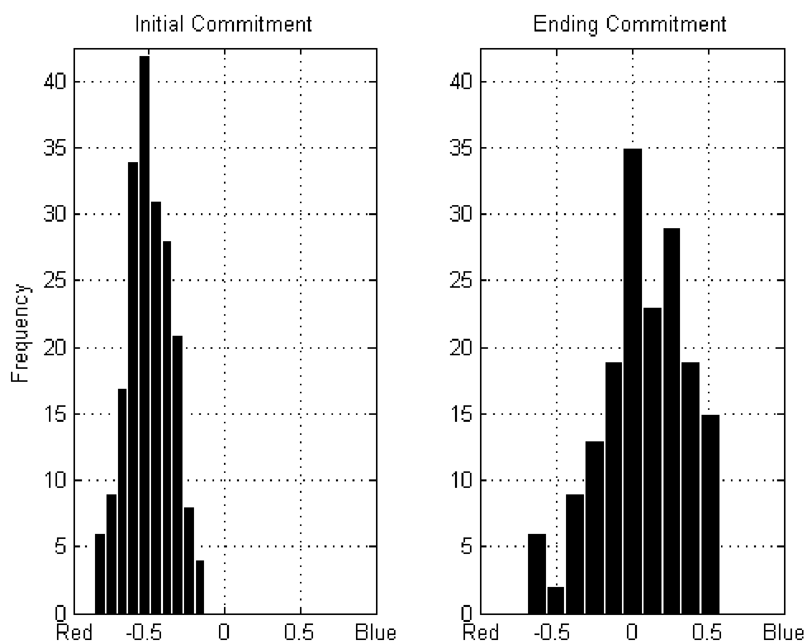



Figure 6: Scenario 2: Blue Effectiveness = 0.8, Accuracy = 0.8; Red Effectiveness = 0.8, Accuracy = 0.2; initial commitment supportive of Blue force (mean = 0.25); no use of indirect fire or IEDs. Soldier and civilian dead counts (top plot) and civilian fear and anger attributes (bottom plot) across the model run (x axis); final statistics (between plots).

By comparing the plots, soldier and civilian deaths occurring at specific time steps correlate to increases in civilian fear and anger. For example during steps 5 to 15, both soldier and civilian deaths increase sharply and nearly in parallel (top plot) resulting in increased civilian fear and anger primarily towards Red force (bottom plot). This pattern is repeated to a lesser extent, during time steps 70 to 90. Several of the final statistics for this run are listed between the plots. More shots fired and a greater number of civilians killed by Red push civilian commitment towards Blue force with an increase in commitment from an initial mean of 0.25 to a final mean of 0.32.

#### Scenario 3: High Effectiveness (0.8), High Accuracy (0.8) for Blue
#### High Effectiveness (0.2), Low Accuracy (0.2, high collateral damage) for Red

In this scenario, low effectiveness and low accuracy characterize Red soldiers' ineffective targeting of Blue soldiers while causing widespread collateral damage. Indirect fire and IEDs are used in this model run resulting in overall higher death counts. The initial commitment distribution is set half way between neutral and strongly supportive of Red force with mean = -0.5 and standard deviation = 0.15. This level of commitment represents an intensity of conflict similar to a civil rebellion or counterinsurgency campaign (see Figure 2 with the distribution labeled CI). A substantial amount of influence is needed to shift commitment in a positive direction towards a more neutral level. With Red force's low effectiveness and accuracy and extensive damage caused by IED detonations, a positive commitment shift is achieved by the end of the model run. Figure 7 shows the shift in civilian commitment to a nearly neutral level along with several of the corresponding final statistics.




| | |
|---|---|
| Red killed by Blue = 10 | Blue killed by Red = 13 |
| Shots fired by Blue = 10 | Shots fired by Red = 6 |
| Blue indirect fire attempts = 0 | Red IED detonation attempts = 3 |
| Civilians killed by Blue = 1 | Civilians killed by Red = 29 |
| Mean initial commitment = -0.5 | Mean final commitment = 0.07 |
| | Mean final human loss = -0.18 |
| | Mean social disruption = -0.33 |

Figure 7: Scenario 3: Blue Effectiveness = 0.8, Accuracy = 0.8; Red Effectiveness = 0.2, Accuracy = 0.2; initial commitment strongly supportive of Red force (mean = -0.5; left plot); use of indirect fire and IEDs. Civilian commitment shifts to a neutral level in response to substantial collateral damage caused by Red force.

### *Results of Repeated Model Runs*

The above plots and tables give a feel for what is happening under the various scenarios. This section shows the interactive effects of effectiveness and accuracy on civilian commitment when multiple model runs per scenario are executed. Table 7 summarizes the results from 25 model runs of 100 ticks in length for each scenario. The results reported in Table 7 are averaged across the 25 model runs.

In Table 7, Scenarios 1A and 1B are the same with the exception of no indirect fire and IEDs used in the runs for 1A, and indirect fire and IEDs used in the runs for 1B. Because effectiveness and accuracy are high (0.8) for both Blue and Red, the results of Scenario1A show almost equivalent low dead soldier counts (4.8 Blue dead, 4.48 Red dead) with approximately one civilian killed by each force (0.6 civilians killed by Blue, 1.04 civilians killed by Red). The civilian death count is low because the probably of collateral damage is low (1 – accuracy of 0.8 = 0.2) and no indirect fire and IEDs were used in this series of runs. There is an insignificant shift in commitment toward Blue from 0.005 to 0.019.

In Scenario 1B, both soldier and civilian deaths increase substantially. When executing indirect fire and IEDs, civilians located within the target area not considered; therefore, civilian dead counts are high (14.44 civilians killed by Blue, 18.48 civilians killed by Red) even through the probably of collateral damage is low. There is a slight shift of commitment towards Blue from 0.005 to 0.085.

Table 7: Average results of multiple model runs (25 runs of 100 ticks) per scenario.

<table>
<tr><th colspan="3">Scenario</th><th>Initial Commitment</th><th>Ending Commitment</th><th>Blue Dead</th><th>Red Dead</th><th>Civilians Killed by Blue</th><th>Civilians Killed by Red</th></tr>
<tr><td colspan="3">1A. No Indirect Fire or IEDs</td><td rowspan="4">0.005</td><td rowspan="4">0.019</td><td rowspan="4">4.80</td><td rowspan="4">4.48</td><td rowspan="4">0.60</td><td rowspan="4">1.04</td></tr>
<tr><td></td><td>Blue</td><td>Red</td></tr>
<tr><td>Effective</td><td>0.8</td><td>0.8</td></tr>
<tr><td>Accuracy</td><td>0.8</td><td>0.8</td></tr>
<tr><td colspan="3">1B. Indirect Fire and IEDs</td><td rowspan="4">0.005</td><td rowspan="4">0.085</td><td rowspan="4">9.72</td><td rowspan="4">8.48</td><td rowspan="4">14.44</td><td rowspan="4">18.48</td></tr>
<tr><td></td><td>Blue</td><td>Red</td></tr>
<tr><td>Effective</td><td>0.8</td><td>0.8</td></tr>
<tr><td>Accuracy</td><td>0.8</td><td>0.8</td></tr>
<tr><td colspan="3">2. No Indirect Fire or IEDs</td><td rowspan="4">0.256</td><td rowspan="4">0.309</td><td rowspan="4">5.44</td><td rowspan="4">5.44</td><td rowspan="4">0.64</td><td rowspan="4">3.12</td></tr>
<tr><td></td><td>Blue</td><td>Red</td></tr>
<tr><td>Effective</td><td>0.8</td><td>0.8</td></tr>
<tr><td>Accuracy</td><td>0.8</td><td>0.2</td></tr>
<tr><td colspan="3">3. Indirect Fire and IEDs</td><td rowspan="4">-0.500</td><td rowspan="4">-0.384</td><td rowspan="4">7.52</td><td rowspan="4">10.12</td><td rowspan="4">12.64</td><td rowspan="4">23.40</td></tr>
<tr><td></td><td>Blue</td><td>Red</td></tr>
<tr><td>Effective</td><td>0.8</td><td>0.8</td></tr>
<tr><td>Accuracy</td><td>0.2</td><td>0.2</td></tr>
</table>

In Scenario 2, the accuracy of Red soldiers is set to 0.2. This low accuracy means there is a high probability for collateral damage (80%). Indirect fire and IEDs are not available for use, and this is reflected in the low soldier and civilian dead counts. Low Red accuracy explains the 3.12 civilians killed by Red compared to 0.64 civilians killed by Blue. The initial civilian commitment distribution has a mean of 0.25 which represents a population slightly supportive of Blue force. Because of the collateral damage caused by Red, the mean ending commitment has shifted in the positive direction to 0.30 showing more support for Blue force.

In Scenario 3, both Red effectiveness and accuracy are set to 0.2 characterizing poor targeting of Blue soldiers and many accidental civilian deaths. Indirect fire and IEDs are available for use producing a large number of soldier and civilian deaths. The combination of poor targeting performance by Red and the use of indirect fire and IEDs produces the greatest differences between Blue and Red soldier deaths (7.52 versus 10.12), and civilians killed by Blue and Red (12.64 versus 23.40) across all scenarios. The initial civilian commitment was strongly supportive of Red (-0.5) and not susceptible to influence which explains the resulting minimal positive shift in commitment (-0.384).

In summary, concerning the parameters controlling direct action: when there is a high to low relationship between Blue and Red effectiveness, the difference is reflected in soldier death counts; when there is a high to low relationship between Blue and Red accuracy, the difference is reflected in civilian death counts; and when indirect fire and IED use is added to the above relationships, all dead counts increase. Concerning shifts in commitment: the effects of direct action shift commitment toward the force causing less death; but the extent of the shift is moderated by the initial level of commitment (i.e., the closer to either end of the scale, the more influence is required to initiate a shift).

## 5. Conclusion and Future Directions

The sparse functionality offered by the simulation environment supports its primary purpose of developing and testing light models of civilian support, in this case, represented by fluctuating levels of commitment towards one or the other combating forces. Civilian commitment shifts dynamically during model runs in response to common direct actions (i.e., individual firing, indirect fire, and IED denotation). For analysis purposes, the state of the agent attributes (i.e., commitment, fear, anger) can be analyzed individually across ticks or in aggregate by comparing initial and final distributions.

Matlab was the ideal programming language to construct an agent-based sandbox for experimentation with simplistic mathematical representations of civilian support. The degree of complexity in the definition of the civilian agent and its interaction with the combative forces depends on the modeler's analysis objectives, the targeted system of use (i.e., when embedding the model in a larger simulation environment), and the computational resources available.

This level of civilian modeling is not detailed enough to forecast civilian behavior; instead, its main intention is to enhance large force-on-force simulations by offering command-level decision makers a persistent remainder of the effects of direct action within highly populated areas of operation.

Several modifications and extensions to the model and simulation sandbox are listed below. These can provide focus for the current and future development of civilian support models. The most obvious modification is to test different mathematical representations of civilian support. Input for the support formulation can come from the set of attributes defining civilian behavior and interactions among agents during the course of the simulation.

When considering sets attributes, there are many alternatives as attributes can represent psychological, cognitive, societal, economic, and even physical characteristics. For example, societal and economic attributes could be used to divide civilians into subpopulations with each civilian belonging to one of several group identities used as a baseline for a support formulation. In this model, civilian interaction with soldiers is limited to situation awareness of firing and becoming collateral damage. An extension to the current stationary civilian would be to add movement, for example, giving civilians the capability of running away when soldiers are detected within the scan area.

In addition to commitment towards the combating forces, civilians feel an emotional reaction of fear and anger. A current limitation is the lack of a mechanism for reversing the amount of fear and anger felt by the civilians. To counter the effects of direct action (which only increase fear and anger), interactions representing incentives or good will gestures could be added to the simulation. For example, soldier agents could engaging in humanitarian aid or marketing campaigns in order to sell their cause to the population with the effect of decreasing fear and anger while hopefully shifting commitment. In the current version of the model the emotional attributes of fear and anger are not well integrated into the attitudinal state of commitment. Adding additional mechanisms to tie these two reactionary behaviors together is necessary.

Lastly, to create a more usable research development platform in general, the current simulation environment requires a graphical user interface (GUI). Ideally, the effects of human loss and collateral damage on civilian support could be parameterized and the associated equations entered by way of a GUI instead of programmed within the simulation itself. A GUI would also allow for assignment of key parameter values such as those controlling attribute distributions, direct action, the battlefield grid, initial soldier and civilian counts, and other runtime settings.

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